Astronomy & Astrophysics manuscript no. 19319ms
March 4, 2013

Letter to the Editor

Detection of a 1.59 h period in the B supergiant star HD 202850*

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Received; accepted

ABSTRACT

Context. Photospheric lines of B-type supergiants show variability in their profile shapes. In addition, their widths are much wider than can be accounted for purely by stellar rotation. This excess broadening is often referred to as macroturbulence. Both effects have been linked to stellar oscillations, but B supergiants have not been systematically searched yet for the presence of especially short-term variability caused by stellar pulsations.
Aims. We have started an observational campaign to investigate the line profile variability of photospheric lines in a sample of Galactic B supergiants. These observations aim to improve our understanding of the physical effects acting in the atmospheres of evolved massive stars.
Methods. We obtained four time-series of high-quality optical spectra for the Galactic B supergiant HD 202850. The spectral coverage of about 500 Å around Hα encompasses the Si II $\lambda\lambda$6347, 6371, and the He I λ6678 photospheric lines. The line profiles were analysed by means of the moment method.
Results. The time-series of the photospheric Si II and He I lines display a simultaneous, periodic variability in their profile shapes. Proper analysis revealed a period of 1.59 h in all three lines. This period is found to be stable with time over the observed span of 19 months. This period is much shorter than the rotation period of the star and might be ascribed to stellar oscillations. Since the star seems to fall outside the currently known pulsational instability domains, the nature of the discovered oscillation remains unclear.

Key words. Stars: early-type – supergiants – Stars: atmospheres – Stars: oscillations – Stars: individual: HD 202850

1. Introduction

Many B-type supergiants are reported to show spectroscopic and photometric variability (e.g., Fullerton et al. 1996; Kaufer et al. 1997, 2006; Lefever et al. 2007; Markova et al. 2008; Clark et al. 2010). In addition, spectral lines of B supergiants are found to be much wider than expected from pure stellar rotation. This extra broadening, which is generally referred to as macroturbulence, can be of the same order as the stellar rotation (e.g., Ryans et al. 2002; Simón-Díaz & Herrero 2007; Markova & Puls 2008). The nature of macroturbulence has long been unclear, although the often high, supersonic value makes a kinematic origin of this broadening rather doubtful.

Lucy (1976) previously suggested that the appearance of this macroturbulence together with spectroscopic and photometric variability could be a result of stellar pulsations. Recently, Aerts et al. (2009) studied the shape of line profiles resulting from a combination of both non-radial pulsations and stellar rotation. They found that numerous superimposed pulsational modes can result in a substantial line width comparable to the rotational one. Observational evidence for the presence of non-radial pulsations in some B supergiants was found from spectroscopy as well as from space-based photometry (Saio et al. 2006; Lefever et al. 2007). Simón-Díaz et al. (2010) found additional evidence for a correlation between macroturbulent broadening and line profile variabilities.

Table 1. Stellar parameters of HD 202850 from Markova & Puls (2008).

$T_{\rm eff}$ [K]	$\log L/L_\odot$	$\log g$ [cgs]	R_* [$R_\odot$]	M [$M_\odot$]	$v\sin i$ [km s^{-1}]	$v_{\rm macro}$ [km s^{-1}]
11 000	4.59	1.87	54	8^{+4}_{-3}	33 ± 2	33 ± 2

The simultaneous presence of macroturbulent broadening and line profile variation in B supergiants hence seems to be directly linked to non-radial pulsations. Most periods identified in B supergiants so far are on the order of days and could be interpreted as classical gravity modes. Interestingly, in the analysis of photometric data for the late-type B supergiant HD 46769 Lefever et al. (2007) found a period of 2.693 h. In addition, the location of this object in the Hertzsprung-Russell diagram falls outside the instability domain calculated by Saio et al. (2006) for evolved massive stars that undergo gravity-mode pulsations. Here, we report on the discovery of another late-type B supergiant, HD 202850, that seems to be located slightly outside this instability domain, but with a short-period variability. HD 202850 (= σ Cyg) is a Galactic supergiant classified as B9 Iab. It is located in the OB association Cyg OB 4 at a distance of ~ 1 kpc (Humphreys 1978). The set of stellar parameters obtained by Markova & Puls (2008) is given in Table 1.

2. Observation and data reduction

We observed HD 202850 on 2010 September 6, 11, and 12 and on 2012 April 30 (see Table 2), using the Coudé spectrograph

* Based on observations performed with the 2m-telescope at Ondřejov Observatory

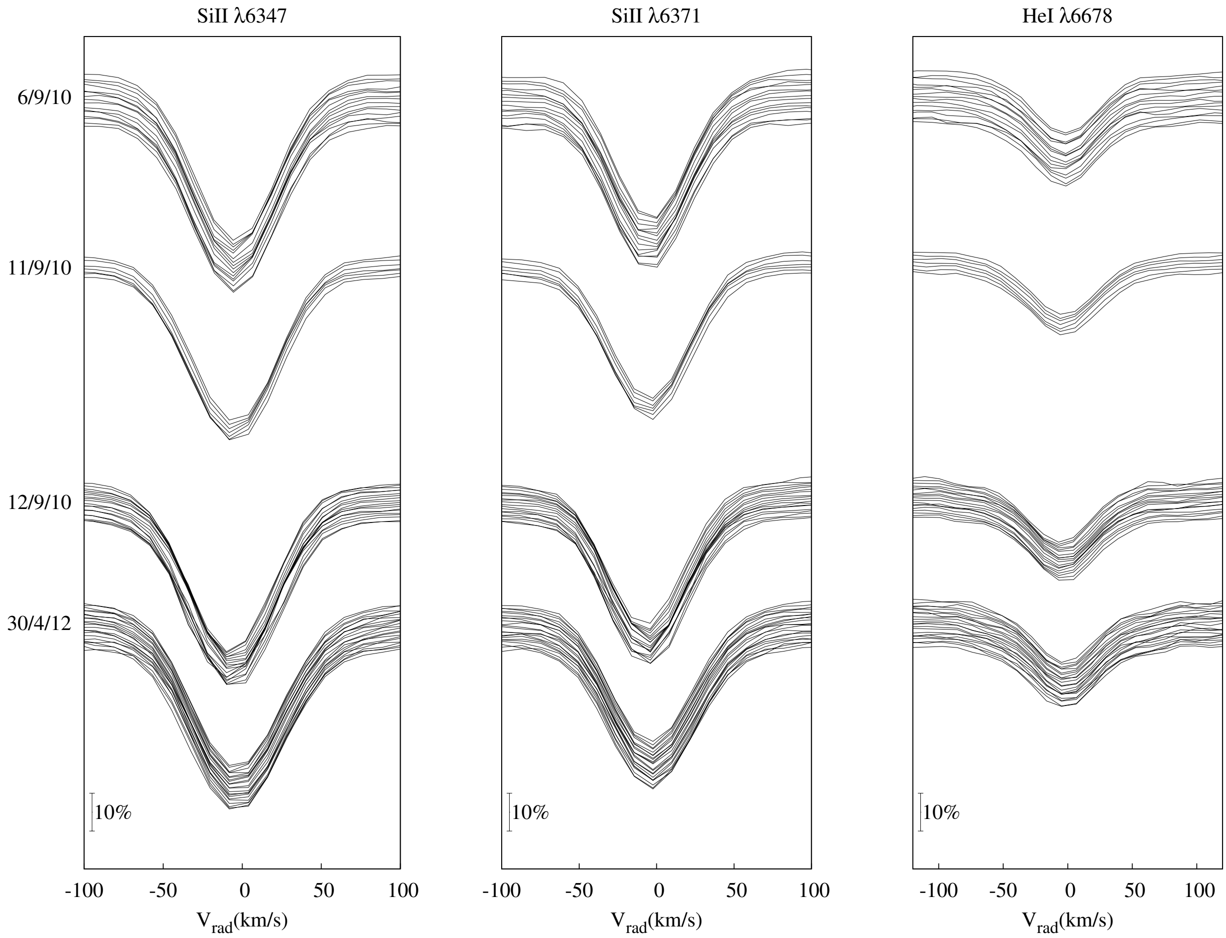

Fig. 1. Time-series of the Si II $\lambda\lambda$6347, 6371 and He I λ6678 lines. The time increases from top to bottom. For better visual inspection consecutive spectra have been slightly shifted along the vertical axis with offsets proportional to the exposure times.

Table 2. Journal of observations. The Heliocentric Julian Date (HJD) refers to the middle of the exposure.

HJD (2450000+)	t_{exp} [s]	HJD (2450000+)	t_{exp} [s]	HJD (2450000+)	t_{exp} [s]
5466.37462	600	5451.53004	600	6048.50304	300
5466.38362	600	5452.32982	250	6048.50843	300
5466.39268	600	5452.33502	300	6048.51384	300
5466.40173	600	5452.34064	300	6048.51925	300
5466.41073	600	5452.34610	300	6048.52465	300
5466.41974	600	5452.35213	300	6048.53005	300
5466.42877	600	5452.35767	300	6048.53547	300
5466.43781	600	5452.36317	300	6048.54087	300
5466.44683	600	5452.36868	300	6048.54629	300
5466.45582	600	5452.37426	300	6048.55170	300
5466.46486	600	5452.37977	300	6048.55710	300
5466.47388	600	5452.38528	300	6048.56252	300
5466.48296	600	5452.39076	300	6048.56794	300
5466.49201	600	5452.39631	300	6048.57336	300
5466.50103	600	5452.40179	300	6048.57877	300
5466.51002	600	5452.40736	300	6048.58416	300
5451.47616	600	5452.41293	300	6048.58957	300
5451.48516	600	5452.41850	300	6048.59496	300
5451.49411	600	5452.42410	300	6048.60036	300
5451.50312	600	5452.42976	300	6048.60576	300
5451.51209	600	6048.49219	300	6048.61125	300
5451.52107	600	6048.49762	300		

attached to the 2-m telescope at Ondřejov Observatory (Šlechta & Škoda 2002). We used the 830.77 lines mm^{-1} grating with a SITe 2030 × 800 CCD that delivered a spectral resolution of $R \simeq 13\,000$ in the Hα region with a wavelength coverage from 6253 Å to 6764 Å. For wavelength calibration, a comparison spectrum of a ThAr lamp was taken immediately after each exposure. The stability of the wavelength scale was verified by measuring the wavelength centroids of O I sky lines. The velocity scale remained stable within 1 km s^{-1}.

The data were reduced and heliocentric velocity corrected using standard IRAF[1] tasks. On each night we also observed a rapidly rotating star (HR 7880, Regulus) to perform the telluric correction. Final ranges in signal-to-noise ratios are 250–500, and the data with the highest quality were those obtained on 2010 September 12.

3. Results

In addition to Hα, our observed spectral range also included the photospheric lines of Si II $\lambda\lambda$6347, 6371, and He I λ6678. Their time-series obtained on the four nights are shown in Fig. 1. A

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

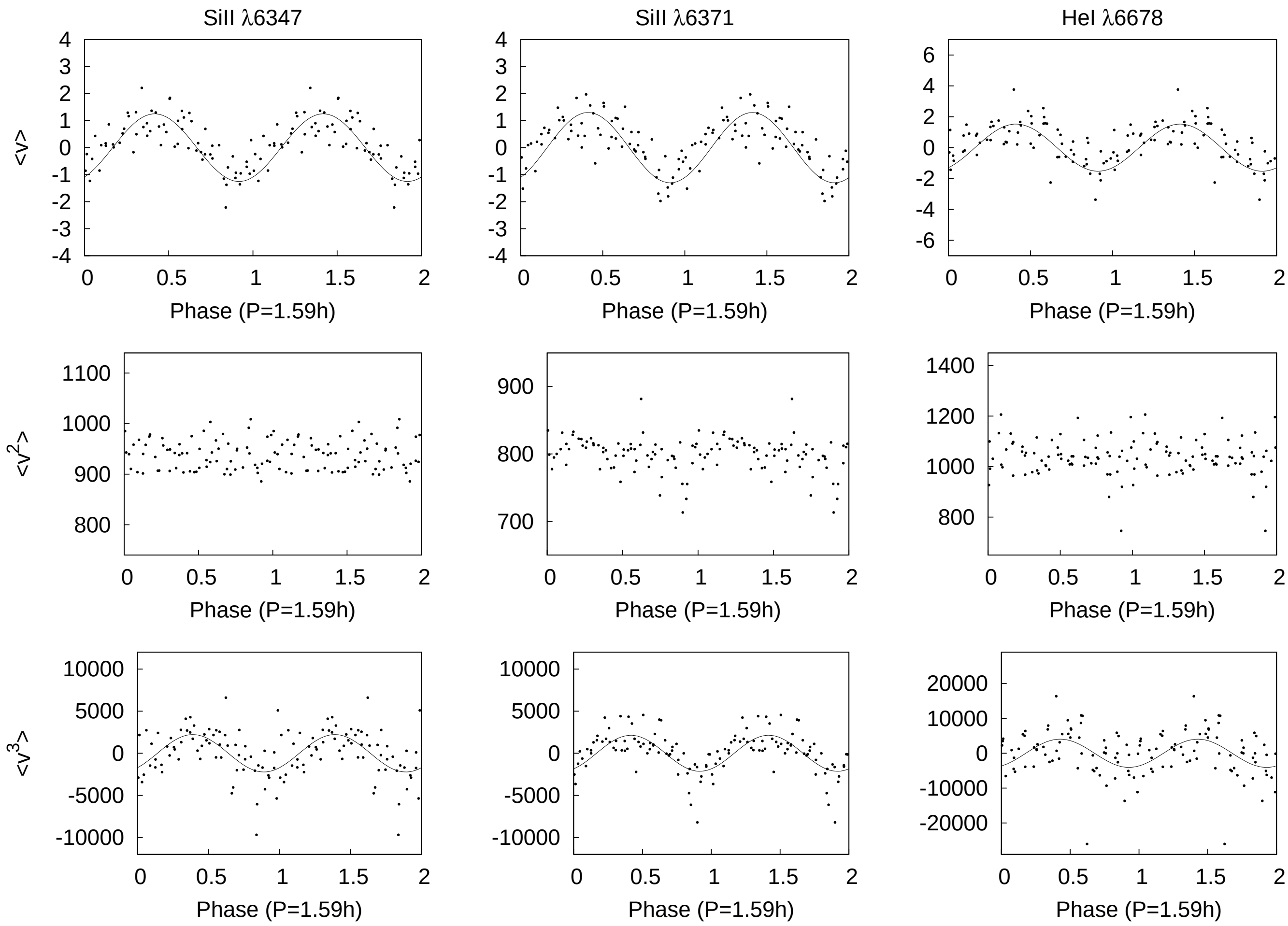

Fig. 2. First three observed moments of the Si II $\lambda\lambda$6347, 6371 and He I λ6678 lines (dots). $< v >$, $< v^2 >$, and $< v^3 >$, have units km s^{-1}, (km s^{-1})^2, and (km s^{-1})^3, respectively. The solid lines represent the best-fit sine curves to the first and third moments.

periodic variation is visible simply from visual inspection, and the behaviour of the variation is similar in all the lines. If the variation is indeed periodic, the period must be shorter than (or similar to) the time span of the observations, which were ~ 3.5, ~ 1.5, ~ 2.5, and ~ 3.0 h.

As mentioned above, line profile variability in B supergiants might be caused by non-radial pulsations. Until now, the associated periods were on the order of days. To check whether pulsations might cause these short-term variations in the line profiles of HD 202850, and to quantify this possible period, we applied the moment method, following the description of Aerts et al. (1992) and North & Paltani (1994). These moments have proven to be excellent tools for studying line profile variabilities because their behaviour allows one to distinguish between different origins of the variability, such as stellar spots, radial and non-radial pulsations. We are aware that the quality of our data, especially the resolution of our spectrograph with only $R \simeq 13\,000$, is not sufficient to perform a successful mode identification, which would require a spectral resolution of $R > 40\,000$ (Zima 2008). Nevertheless, the moment method applied to our data will unveil a possible periodicity in the line profiles.

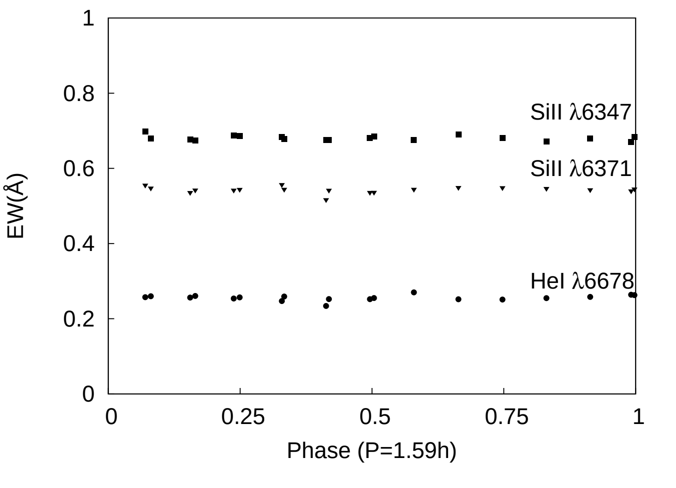

Fig. 3. Stability in equivalent widths of the three photospheric lines. Shown are the phased data from 2010 Sep. 12, which have the highest quality.

For He I and the Si II lines, the results of the moment calculations for the combined data set of all four time-series are displayed in Fig. 2. The moments are plotted versus phase, using the period obtained from two different methods applied to the first moments of the two nights with the shortest exposure times: (i) a simple sine curve fit and (ii) a more sophisticated Fourier analysis. The period obtained from all three lines applying both methods is $P = 1.59 \pm 0.01$ h. The moments obtained from the time-series in the other two nights were phased with the same period. Although these longer exposure observations suffer from

some smearing effects, their moments still display the same periodic behaviour.

4. Discussion

The moment analysis delivers important insight into the possible nature of the line profile variability. The simultaneous variation in the line profiles of both helium and metal lines means that the presence of stellar spots can be excluded with a high probability. These spots are common in chemically peculiar stars and are usually related to surface inhomogeneities in the form of over- and under-abundances in different elements. The photospheric line profiles of these elements hence vary with the rotation period of the star, and the variations in the lines from different elements are typically not identical (e.g., Briquet et al. 2001, 2004; Lehmann et al. 2006). In addition, stars with a patchy surface abundance pattern are known to show rotationally modulated light variability (Krtička et al. 2007, 2009). From the Hipparcos light-curve of HD 202850, Koen & Eyer (2002) derived a putative (but not yet confirmed) period of 120.2 d. This period might be caused by stellar rotation, but the value of $\upsilon \sin i = 33 \pm 2\,\mathrm{km\,s^{-1}}$ obtained by Markova & Puls (2008) limits the rotation period to $P \leq (83 \pm 5)$ d.

The presence of an equal contribution of macroturbulent and rotational broadening in the line profiles of HD 202850 (see Table 1) together with the simultaneous variation in the moments of both the He I and the Si II lines seems therefore to speak in favour of pulsations as the origin of the line profile variations.

The equivalent widths of the lines phased to the 1.59 h period (Fig. 3) do not show a periodic variability, but like most pulsating stars have variations of a few percent at most (e.g., De Ridder et al. 2002). The simple sine curve fits to the third moments (Fig. 2) imply that these moments are dominated by the main frequency. The second moments show a large scatter that makes it difficult to claim specific variations, although indications for a possible double sine (corresponding to twice the main frequency) seem to be present (especially for Si II λ6371), which would speak in favour of an axisymmetric mode. However, these moments suffer strongest from the noise introduced by the signal-to-noise ratio and the relatively low resolution of the data, which severely hampers a proper analysis of their real variations. Hence from the quality of our data we are only able to confirm the presence of the period. For a proper mode identification, spectroscopic data with much higher resolution and signal-to-noise ratio are needed.

While periods on the order of hours are common for non-radially pulsating stars e.g. on the main sequence (e.g. Smith 1977), pulsation periods in B supergiants have been reported to be on the order of days from both observations and theory. Our period of less than 2 h therefore does not seem to fit into the currently known domain of non-radially pulsating supergiants.

In a recent study, Lefever et al. (2007) searched for periodicities in the Hipparcos data of a sample of B supergiants. The shortest period they found was 0.1122 d (= 2.693 h) for the B8 Ib supergiant star HD 46769. While Lefever et al. (2007) did not comment on the period found for this star in more detail, it is interesting to report here that our object, with very similar stellar parameters, falls, like HD 46769, just outside the currently known instability domains for gravity modes discovered in evolved (post-main sequence) stars (Lefever et al. 2007, Saio et al. 2006). This could mean that in late-type B supergiants other yet unknown oscillation modes with periods of a few hours might play a non-negligable role as well.

5. Conclusions

We reported on the discovery of a 1.59 h period in the Galactic late-type B supergiant star HD 202850. This period was found based on time-series of optical spectroscopic observations obtained on four different nights distributed over a time interval of 19 months. Our data reveal simultaneous line profile variations in photospheric lines of Si II $\lambda\lambda$6347, 6371 and He I λ6678. A moment analysis of these lines shows that all lines vary simultaneously in both the radial velocity and the skewness of the line profile, while the equivalent widths of the lines do not change noticeably over the time span of the observations. The second moment is too noisy to allow a proper analysis, but a variation according to an axisymmetric mode might be present. The interpretation of these results excludes the scenario of a chemically peculiar star with surface abundance inhomogeneities in the form of spots. Instead, the results speak in favour of pulsations as a plausible origin of the observed variations. While non-radial pulsations in B supergiants have been identified previously as due to gravity modes with periods on the order of days, our discovery of the second late-type B supergiant with a period on the order of hours might open new perspectives in the studies of asteroseismology in both observations and theory. We hence intend to persue higher resolution spectroscopic time-series to determine the underlying physical process that causes the short-term variations discovered in the late B-type supergiant HD 202850.

Acknowledgements. We thank the anonymous referee for the valuable comments on the manuscript. This research made use of the NASA Astrophysics Data System (ADS). M.K. and M.E.O. acknowledge financial support from GAČR under grant number P209/11/1198. The Astronomical Institute Ondřejov is supported by the project RVO:67985815.

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